

March 22, 1966

C. F. WINTER

3,242,491

INVERTED V-BEAM ANTENNA SYSTEM

Filed Dec. 12, 1962

3 Sheets-Sheet 1

FIG. 1

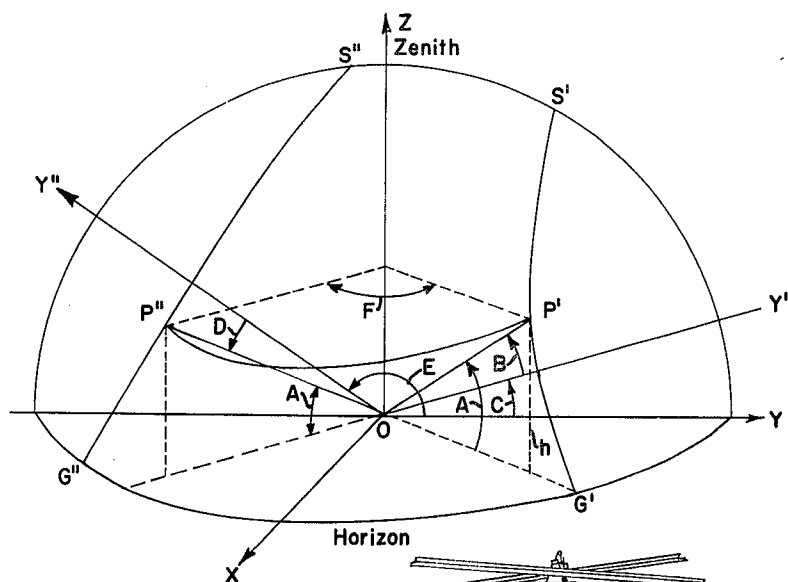


FIG. 2

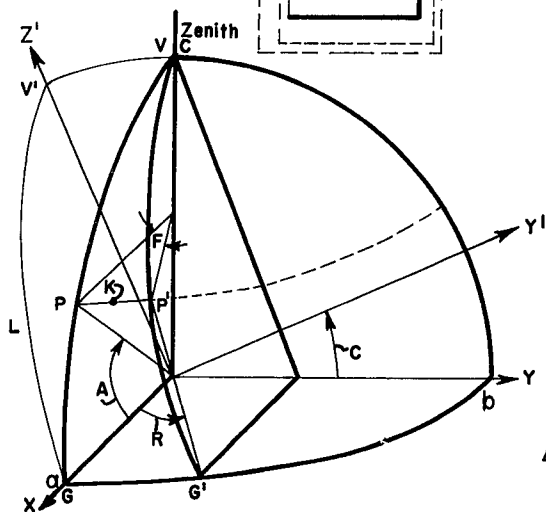
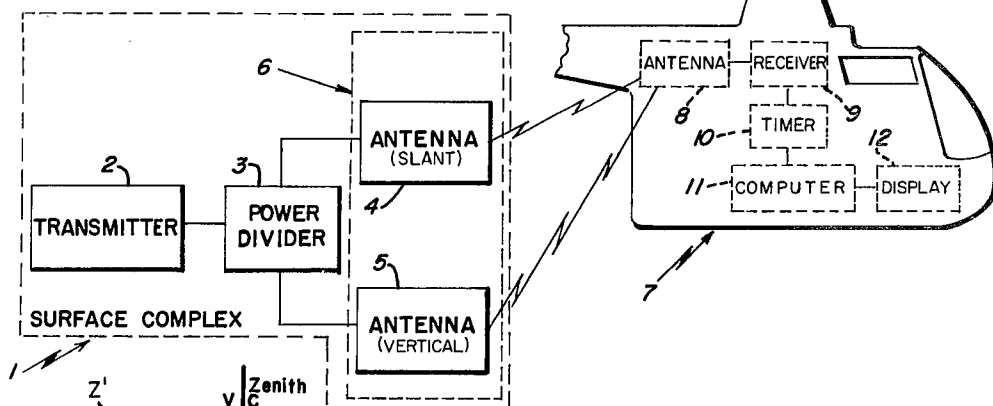


FIG. 3

INVENTOR
CHARLES F. WINTER

BY *Herbert W. Arnold*
ATTORNEY

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C. F. WINTER

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FIG 4

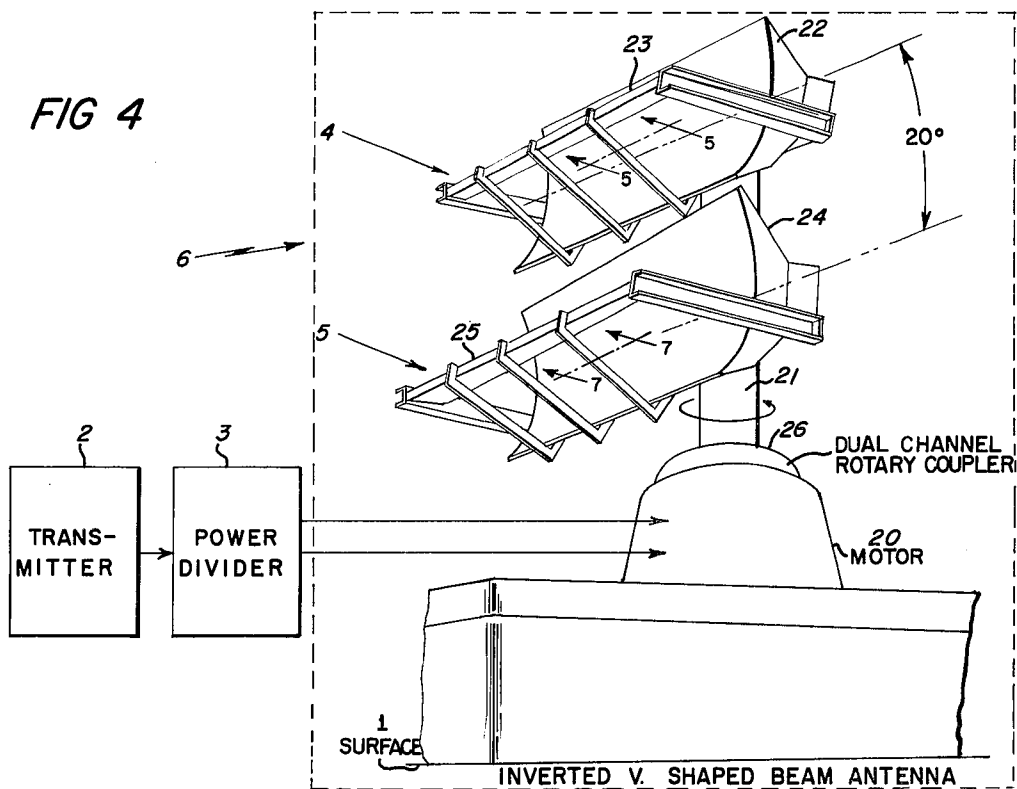


FIG. 5

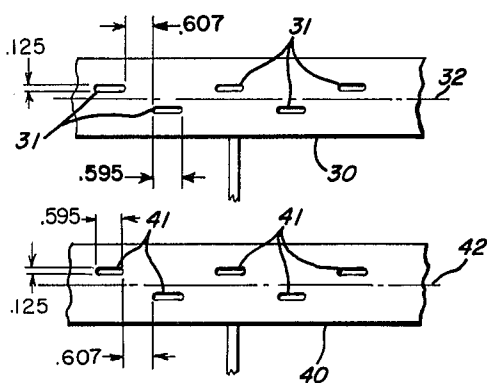


FIG. 7

FIG. 6

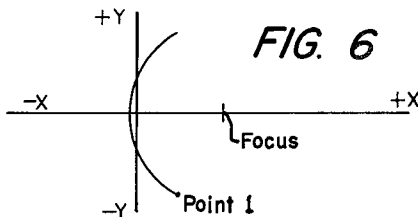
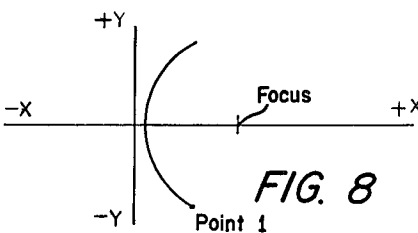


FIG. 8



INVENTOR
CHARLES F. WINTER

BY *Herbert W. Arnold*
ATTORNEY

March 22, 1966

C. F. WINTER

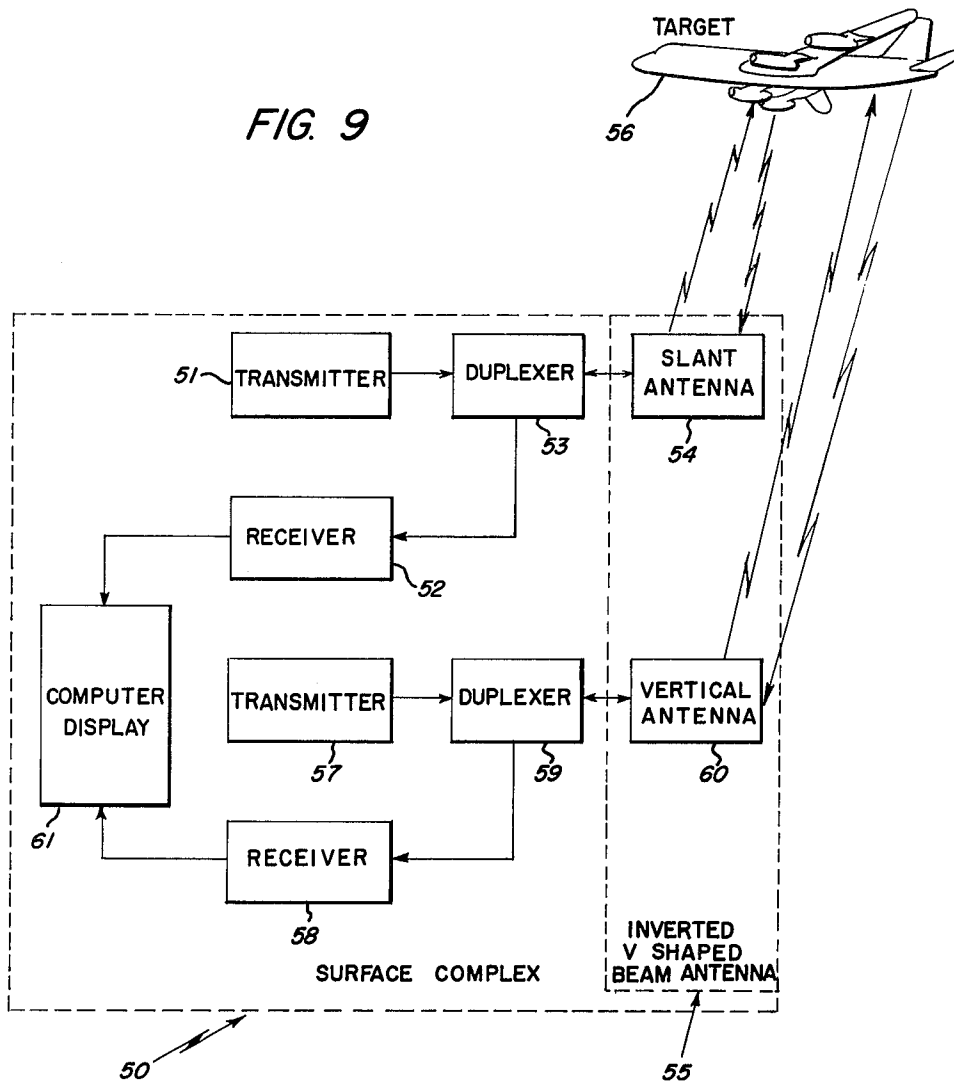
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FIG. 9



INVENTOR

CHARLES F. WINTER

BY *Herbert W. Arnold*

ATTORNEY

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INVERTED V-BEAM ANTENNA SYSTEM

Charles F. Winter, Wrentham, Mass., assignor to Raytheon Company, Lexington, Mass., a corporation of Delaware

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14 Claims. (Cl. 343-11)

The present invention relates to shaped beam antenna systems, and, more particularly, to a system which orients at least one beam of a plurality of shaped beams along a small circle arc.

The majority of three-coordinate guidance and detection antenna systems lack the capability of handling an unlimited number of airborne vehicles, particularly for landing operations requiring accurate angles of descent unless preselected azimuth and elevation approach bearings are utilized. For the prior shaped beam antenna art, see, "Antenna Engineering Handbook," Henry Jasik, McGraw-Hill Book Company, Inc., 1961, particularly chapter 9, etc., and "Microwave Antenna Theory and Design," Samuel Silver, Editor, McGraw-Hill Book Company, Inc., 1949, particularly chapter 13 and chapter 12, Simple Fanned-Beam Antennas, inasmuch as a fanned beam is considered a shaped beam for the purposes of this invention, for a definition and explanation of shaped beams and the types of antennas which can be used to radiate shaped beams. This art teaches a V-beam antenna system which shows the greatest potential for meeting the problem of handling an unlimited number of airborne vehicles. The V-beam approach towards meeting this problem of providing target elevation dates back to World War II; however, to the present time, the disadvantages have outweighed the advantages.

The simple V-beam radiation coverage consists of two distinct beams, each of said beams lying on great circles of a sphere and having their antennas positioned at the center of said sphere no matter what position either of the antennas radiating the beams are slanted, and both shaped in their vertical directions and of narrow beam widths in any azimuthal plane. The definition of a great circle and a small circle are found in "Webster's New International Dictionary," 2nd edition unabridged, which under the heading of "Circles of Sphere" states "a circle upon the surface of the sphere, specifically of the earth or of the heavens, called a great circle when its plane passes through the center of the sphere; in all other cases, a small circle," is adopted in this specification as being definitive of the above words, great circle and small circle. One beam is oriented in the conventional shaped-beam search fashion, i.e., the plane in which the shaping occurs makes an angle of 90° with the horizon plane for any azimuthal pointing of the antenna. The other beam is tilted over at a slant, i.e., its plane of shaping makes an angle of less than 90° with the horizon. When this beam system rotates at a constant rate about the vertical axis, a stationary airborne vehicle may be hit by radiations from both antennas. The angle between hits (which can be determined by a time measurement) can be seen to be a function of the elevation angle of the airborne target. If the tilt angle of the slant antenna is known, then it is possible to solve for the tangent of the angle between beam hits and, therefore,

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establish a relationship between elevation angle versus the angle between beam hits so as to, at all points, determine the angle of descent of said airborne vehicle.

The principal disadvantages of a simple V-beam antenna are that the highest elevation angle that can be determined is a function of the tilt angle. A large tilt angle with respect to the horizontal severely limits elevation coverage for two reasons. First, the slant beam never rises above the complement of the tilt angle. Second, the angle between hits becomes progressively wider as the elevation angle increases. Furthermore, the rate of change of the slope for each radiation curve is a minimum at low elevation angles and, therefore, sensitivity is least near the horizon instead of at the higher angles where accuracy for ground based applications is typically less critical. Additionally, the difference between slope angles on any radiation curve at two elevation angles represents the amount of rotation that a linearly polarized field vector undergoes and, therefore, for a one way beacon V-beam transmission approach, signal loss at the receiving antenna generally results because of the misalignment between the polarizations of the receiving and transmitting antennas.

Therefore, an object of the invention is to provide an improved antenna system which is capable of providing accurate elevation measurements over a broad range of angles and simultaneously of providing the greatest sensitivity of measurement at the low elevation of angles.

In accordance with this invention, an inverted V-shaped beam antenna system, such as used in a beacon guidance system, comprises a transmitter providing energy to a first means for radiating a shaped beam along a great circle and to a second means for radiating a shaped beam along a small circle. Additionally, a system used as a three dimensional or 3D radar, having height finding as one of its functions, comprises a first transmitter, providing energy to an isolation means, such as a duplexer to a first means for radiating a shaped beam along a great circle and a second transmitter, providing energy through a second isolation means to a second means for radiating a shaped beam along a small circle, and a receiver-computer coupled to each of said isolation means for determining a target's position in 3D. By radiating at least one of the beams along a small circle which passes through or sufficiently close to the zenith, the spread between the two beams decreases with increasing elevation, and sensitivity is greatest near the horizon.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, wherein:

FIG. 1 illustrates a geometry for an inverted V-beam antenna system showing arcs of radiation along two small circles,

FIG. 2 illustrates a beacon helicopter system in block form utilizing an inverted V-shaped beam antenna,

FIG. 3 illustrates a geometry of the beacon helicopter system of FIG. 2 having an inverted V-shaped beam antenna radiating arcs of radiation along one great circle and one small circle,

FIG. 4 illustrates a pair of shaped beam antennas for use as an inverted V-shaped beam antenna of FIG. 2,

FIG. 5 illustrates a section of the feed of the slant antenna of FIG. 4,

FIG. 6 illustrates the curvature of the reflector of the slant antenna of FIG. 4.

FIG. 7 illustrates a section of the feed of the vertical antenna of FIG. 4.

FIG. 8 illustrates the curvature of the reflector of the vertical antenna of FIG. 4, and

FIG. 9 illustrates an arrangement of a three dimensional or 3D radar system in block form utilizing an inverted V-shaped beam antenna.

Referring particularly to FIG. 1, there is shown an illustration of a geometry for an inverted V beam antenna system showing arcs of radiation along two small circles. It should be understood that this invention is not limited to two shaped beams, nor is it limited to radiations along small circles; great circle radiations can also be used provided there is at least one shaped beam of a plurality of shaped beams which is oriented along a small circle arc. Particularly, FIG. 1 shows a representation of two shaped beams oriented upon spatial loci, previously unconsidered, which are used to establish one particular spatial coordinate. Typically, this coordinate can be the elevation angle A as shown in FIG. 1. One shaped beam is oriented along the locus of intersection of a unit sphere whose center is at a point 0 and a cone about Y' axis whose cone angle is 2B and whose vertex is at point 0. This locus is the small circle G', P', S' of the sphere for $B \neq 90^\circ$. The Y' axis makes an angle C with the Y axis. For simplicity, the Y' axis is shown in the YZ-plane but this is not a restriction on the principle of the invention. The second shaped beam lies along the locus of intersection of the same sphere and a cone about the Y'' axis whose cone angle is 2D and whose vertex is also at point 0. This locus is the small circle G'', P'', S'' for $D \neq 90^\circ$. The Y'' axis makes an angle E with the Y axis and again, for simplicity only, is pictured in the YZ-plane. According to the values assigned to the angles C, B, E and D, a functional relationship, for example, between the elevation angle A and the angle F measured in a plane parallel to the XY-plane can be solved mathematically for the coordinate A, for each determination of the angle F existing between the corresponding points P', P'', one on each shaped beam at the same height h above the XY-plane. Thus, this arrangement is illustrative of the basic principles involved in considering shaped beams oriented along small circle arcs.

Referring particularly to FIG. 2, there is shown a general arrangement of a beacon helicopter system in block form utilizing an inverted V beam antenna sub-system. There is shown a surface complex 1 having a transmitter 2 of the type generally used in radar systems which could comprise either magnetron or traveling wave tube power amplifiers or other types of power amplifiers to generate a source of electromagnetic radiation. A power divider 3 is coupled to the transmitter 2 and, in turn, a slant antenna 4 and a vertical antenna 5, which are adapted for rotation in the surface complex 1 and which comprise the inverted V-beam antenna 6, are coupled to power divider 3. Antenna 4 produces a shaped beam, which will hereafter be called the slant beam which is directed along a small circle arc and the antenna 5, which hereafter will be referred to as the vertical beam antenna, has its radiation directed along a great circle arc. There is also shown a helicopter 7 in a spaced relationship to the surface complex 1. Helicopter 7 includes an antenna 8 for receiving radiations from antennas 4 and 5 of inverted V-beam antenna 6, a receiver 9 coupled to antenna 8 for detecting the radiations of antennas 4 and 5 from inverted V-beam antenna 6, a timer 10 coupled to the receiver 9 for timing the timed difference in the detection of radiations from antennas 4 and 5 from inverted V-beam antenna 6, computer 11 coupled to the timer 10 for calculating the angle of descent of said helicopter 7 to said surface complex 1 and a display 12 for displaying the angle of descent information to the pilot of helicopter 7.

Referring particularly to FIG. 3 and simultaneously

considering the operation of the system of FIG. 2, there is shown the geometry of a ground complex surface based beacon helicopter landing system as shown in FIG. 2 having an inverted V-beam antenna sub-system radiating arcs of radiation along one great circle and one small circle. The antennas 4 and 5 of the inverted V-beam antenna 6 are positioned at point 0, point 0 being the center of the sphere of which one octant *abc* is shown in FIG. 3. In the XY and Z rectangular coordinates pictured, the XY-plane represents the surface and the Z axis points to the zenith of the sphere. The shaped beam, approximately 1.5° beamwidth in this case, of the antenna 4, hereafter referred to as the slant beam antenna, is directed along the small circle arc G'P'V' constructed about the Y' axis and passing through the zenith point V. This small circle arc is seen to be parallel to only one great circle GLV' on the sphere. The shaped beam, approximately 1.5° beamwidth in this case, of the antenna 5, hereafter called the vertical beam antenna, is directed along a great circle arc GPV. The significant radiation of the vertically shaped beam from the vertical beam antenna 5 is contained between the elevation angles of approximately 6° to 75° along the great circle arc GPV.

The two shaped beams from antennas 4 and 5 are oriented such that the beam from the vertical beam antenna along the arc GPV is functioning in a conventional search radar fashion and that of the slant beam along a small circle arc G'P'V in a previously unconventional manner. Next, it is shown that by rotating the inverted V-beam antenna 6 about point 0 in the surface plane at a constant rate about the Z axis, it is possible that use be made of the angle F, hereafter called the azimuth-response angle, between two points P and P', one on each shaped beam in order to determine the angle of descent that an airborne vehicle, such as helicopter 7 of FIG. 2, hovering on an arc between the points P and P', represented by point K, must maintain to arrive at a predetermined point over the surface complex 1.

As the surface based inverted V-beam antenna rotates, consider the effect as seen by a non-directive or omni receiving antenna, such as antenna 8 of helicopter 7 and a detector receiver 9 installed in an airborne helicopter, such as airborne helicopter 7 of FIG. 2, which is hovering at a given altitude which is represented by point K on an arc or a line connecting points P and P' on the shaped beams from antennas 4 and 5 of FIG. 2. Both beams radiated by the inverted V beam antenna 6 will be received and detected sequentially by the helicopter 7. The azimuth-response angle F can be determined by measuring the time between successive detections of the radiation beams from antennas 4 and 5 by the combination of the timer 10 and the receiver 9 of helicopter 7, dividing this time by the time for one rotation of the inverted V-beam beacon antenna sub-system 6 and multiplying the resulting fraction by 360° . It is therefore seen that the period between detection increases in duration as the helicopter moves toward a lower elevation due to increase in spread between the beams at lower elevations. The elevation angle A of FIG. 3 can be determined by the computer 11 of helicopter 7 using the timing information from timer 10 to solve the equation

$$\sin F = \frac{\sin R}{\cos A} + \tan C \tan A$$

for the angle A where the angles R and C are known parameters of the inverted V-beam antenna 6 in relation to surface complex 1. Knowing that the angle of descent equals the elevation angle A, one particular coordinate in space, with the helicopter as a reference, has been established which can then be displayed by display 12 so that the pilot of helicopter 7 may guide the helicopter 7 to a landing area of surface complex 1.

Referring particularly to FIG. 4, there is shown a pair of shaped beam antennas utilized as an inverted V-shaped beam antenna. Although these antennas 4 and 5 are physically separated by 20°, such displacement is so minute that for all practical purposes it is considered that they are both located at the same point in space. There is shown a surface complex 1 having a transmitter 2, a power divider 3 coupled to the transmitter 2 and an inverted V-shaped beam antenna 6 coupled to power divider 3. Inverted V-shaped beam antenna 6 comprises a motor 20 for rotating shaft 21. There is shown mounted on shaft 21 a slant antenna 4 tilted at a 20° angle with the horizontal surface 1. Slant beam antenna 4 comprises a reflector 22 and a slotted aperture feed 23 positioned at the focal point of reflector 22. Additionally, mounted on shaft 21 is shown vertical antenna 5 positioned parallel to surface 1 and rotated 10° with respect to slant antenna 4 about shaft 21. Vertical antenna 5 comprises a reflector 24 and a slotted aperture feed 25 positioned at the focal point of reflector 24. Additionally, there is shown, mounted on motor 20, a dual channel rotary coupler for feeding energy from power divider 3 to each of the antenna feeds 23 and 25. The phasing of the antenna feeds causes the antenna beam to radiate along a large or small circle.

Referring particularly to FIG. 5 and simultaneously to FIGS. 2 and 4, there is shown a section 30 of a feed 23 of slant antenna 4 to illustrate the slotted aperture dimensions of the feed directed toward the reflector 22. For example, in the present embodiment at an operating frequency of 9375 megacycles, section 30 of feed 23 comprises a piece of RG-52U waveguide having interior dimensions .900" by .400". The waveguide feed 23 comprises an aperture 67" in length having a plurality of slots 31, numbering 110 overall, each .595" long and .125" wide, and being spaced .607" from each other. The spacing and the number of slots has been determined in order to provide a half power beamwidth of 1.5° in the azimuth-response plane. The slot spacing is determined from Taylor's beamwidth aperture length relationship for a 35-db sidelobe level, see T. T. Taylor, "Design of Line Sources for Narrow Beamwidth and Low Sidelobes," Tech. Memo No. 316, Hughes Aircraft Company, July 31, 1953, ASTIA Document Contract No. AF19(604)-262-F8, July 31, 1953 and "Design of Line-Source Antennas for Narrow Beamwidths and Low Sidelobes," IRE Transaction on Antennas and Propagation AP-3(1), pp. 16-28, January, 1955, and the standard beam direction formula

$$\alpha = \frac{\lambda}{\lambda g} \frac{\lambda}{2s}$$

where α represents the phase front inclination to the normal of the waveguide, and where λg =guide wave-length and s =the inter-element spacing, see H. Jasik, "Antenna Engineering Handbook," McGraw-Hill, New York, pp. 9-11, 9-14, particularly Equations 9-20 on page 9-13, 1961. It is to be understood that the spacings can be determined for other frequencies and other half power beamwidths by the above method and using the references as cited above. Each of the slots 31 are spaced from the centerline 32 of the waveguide 30 as shown in the accompanying Table A, beginning with slot #1 and ending with slot #110.

The displacement of the slots from the centerline is determined in accordance with the amount of energy to be extracted from the waveguide feed. The displacements are found successively, starting with the slot farthest from the input and using Jasik, "Antenna Engineering Handbook," McGraw-Hill, 1961, sections 9-11 through 9-14 for 9375 megacycles. It is to be understood that other spacings would be obtained at different operating frequencies and the said spacing at other operating frequencies could be obtained by one skilled in the art using the above references.

TABLE A.—110 ELEMENT SLOT DISPLACEMENT FROM CENTERLINE

Slot No.	Centerline Displacement (Inches)	Slot No.	Centerline Displacement (Inches)	Slot No.	Centerline Displacement (Inches)
1	0.005 Left	38	0.030 R	75	0.064 L
2	.005 Right	39	.031 L	76	.065 R
3	.006 L	40	.032 R	77	.066 L
4	.006 R	41	.033 L	78	.066 R
5	.006 L	42	.033 R	79	.067 L
6	.007 R	43	.034 L	80	.068 R
7	.007 L	44	.035 R	81	.068 L
8	.007 R	45	.036 L	82	.068 R
9	.008 L	46	.037 R	83	.069 L
10	.008 R	47	.038 L	84	.069 R
11	.008 L	48	.039 R	85	.069 L
12	.009 R	49	.040 L	86	.069 R
13	.009 L	50	.041 R	87	.069 L
14	.010 R	51	.042 L	88	.068 R
15	.011 L	52	.043 R	89	.068 L
16	.011 R	53	.044 L	90	.067 R
17	.012 L	54	.045 R	91	.066 L
18	.013 R	55	.046 L	92	.065 R
19	.014 L	56	.047 R	93	.064 L
20	.014 R	57	.048 L	94	.062 R
21	.015 L	58	.049 R	95	.060 L
22	.016 R	59	.050 L	96	.058 R
23	.016 L	60	.051 R	97	.056 L
24	.017 R	61	.052 L	98	.054 R
25	.018 L	62	.052 R	99	.052 L
26	.019 R	63	.053 L	100	.049 R
27	.020 L	64	.054 R	101	.047 L
28	.021 R	65	.055 L	102	.045 R
29	.022 L	66	.056 R	103	.044 L
30	.022 R	67	.057 L	104	.042 R
31	.023 L	68	.058 R	105	.040 L
32	.024 R	69	.059 L	106	.039 R
33	.025 L	70	.060 R	107	.038 L
34	.026 R	71	.061 L	108	.038 R
35	.027 L	72	.062 R	109	.038 L
36	.028 R	73	.063 L	110	.038 R
37	.029 L	74	.064 R	Load	

Referring particularly to FIG. 6 and simultaneously to FIGS. 2 and 4, there is shown the curvature of reflector 22 of slant antenna 4. For example, at 9375 megacycles, the focus of reflector 22 is at a point 15.0" along the positive X axis of FIG. 6. The curvature of the reflector is represented by the accompanying Table B, showing X and Y coordinates of the curvature. Particularly point 1 along the curvature is seen from the Table B to be +4.624" along the X axis and -7.538" along the Y axis. The other points 2-38 are similarly obtained from the accompanying Table B. The design of the curvature of the slant beam reflector is based on geometrical optics considerations. The standard technique appears in the literature, S. Silver, "Microwave Antenna Theory and Design," McGraw-Hill, New York, pp. 497-500, 1949; A. S. Dunbar, "Calculations of Doubly Curved Reflectors for Shaped Beams," Proc. IRE, vol. 36, pp. 1289-1296, October 1948; H. Jasik, "Antenna Engineering Handbook," McGraw-Hill, New York, pp. 12-19 to 12-21, 1961. Referring particularly to Jasik, section 12-20 and solving the equation

$$\frac{\int_{\theta_1}^{\theta} P(\theta) d\theta}{\int_{\theta_1}^{\theta_2} P(\theta) d\theta} = \frac{\int_{\phi_1}^{\phi} I(\phi) d\phi}{\int_{\phi_1}^{\phi_2} I(\phi) d\phi}$$

where ϕ and θ are the primary—and secondary—pattern angle and the subscript values corresponding to the reflector limits and where the energy corresponding between primary $I(\phi)$ and secondary power beam pattern $P(\theta)$ is expressed by the above formula, the coordinates as shown in Table B are obtained. It is to be understood that for other operating frequencies the coordinates of the reflector will vary in accordance with known solutions of the above formula.

TABLE B.—SLANT REFLECTOR

Point	X (Inches)	Y (Inches)	Point	X (Inches)	Y (Inches)
1.....	4.624	-7.538	20.....	-0.056	2.547
2.....	4.149	-7.210	21.....	-0.008	3.190
3.....	3.658	-6.869	22.....	+0.057	3.837
4.....	3.172	-6.502	23.....	0.140	4.486
5.....	2.696	-6.108	24.....	0.240	5.143
6.....	2.235	-5.683	25.....	0.358	5.790
7.....	1.799	-5.227	26.....	0.492	6.457
8.....	1.404	-4.735	27.....	0.641	7.129
9.....	1.064	-4.207	28.....	0.806	7.808
10.....	0.776	-3.652	29.....	0.990	8.485
11.....	0.542	-3.073	30.....	1.190	9.175
12.....	0.352	-2.478	31.....	1.409	9.874
13.....	0.203	-1.869	32.....	1.647	10.583
14.....	0.088	-1.252	33.....	1.907	11.302
15.....	+0.004	-0.629	34.....	2.187	12.032
16.....	-0.054	0.000	35.....	2.490	12.775
17.....	-0.086	+0.632	36.....	2.817	13.530
18.....	-0.096	1.268	37.....	3.169	14.301
19.....	-0.085	1.906	38.....	3.549	15.085

Referring particularly to FIG. 7 and simultaneously to FIGS. 2 and 4, there is shown a section of feed 25 of vertical antenna 5 to illustrate the slotted aperture dimensions of the feed directed toward the reflector 24. For example, at 9375 megacycles there is shown a section 40 of feed 25 comprising a piece of RG-52U waveguide having interior dimensions .900" x .400". The waveguide feed 25 comprises an aperture 60" in length having a plurality of slots 41, numbering 63 overall, each .630" long and .125" wide, and being spaced .950" from each other. The spacing and the number of slots has also been determined for the vertical antenna in order to provide a half power beamwidth of 1.5° in the azimuth-response plane. The slot spacing is also determined from Taylor's beamwidth aperture length relationship for a 35-db side-lobe level, see T. T. Taylor, "Design of Line Sources for Narrow Beamwidth and Low Sidelobes," Tech. Memo No. 316, Hughes Aircraft Company, July 31, 1953, ASTIA Document Contract No. AF19(604)-262-F8, July 31, 1953 and "Design of Line-Source Antennas for Narrow Beamwidths and Low Sidelobes," IRE Transaction on Antennas and Propagation AP-3(1) pp. 16-28, January 1955, and the standard beam direction formula

$$\sin \alpha = \frac{\lambda}{\lambda g} - \frac{\lambda}{2s}$$

where α represents the phase front inclination to the normal of the waveguide, and where λg = guidewave length and s = the inter-element spacing, see H. Jasik, "Antenna Engineering Handbook," McGraw-Hill, New York, pp. 9-11, 9-14, particularly Equations 9-20 on pages 9-13, 1961. It is to be understood that the spacings can be determined for other frequencies and other half power beamwidths by the above method and using the references as cited above. Each of the slots 41 are spaced from the centerline 42 of the feed waveguide 40, as shown in the accompanying Table C, beginning with Slot #1 and ending with Slot #63. The displacement of the slots from the centerline is determined considering the amount of energy to be extracted from the waveguide feed. The displacements are found successively, starting with the slot farthest from the input and using Jasik, "Antenna Engineering Handbook," McGraw-Hill, 1961, sections 9-11 through 9-14 for 9375 megacycles. It is to be understood that other spacings would be obtained at different operating frequencies and the said spacing at other operating frequencies could be obtained by one skilled in the art using the above references.

TABLE C.—63 ELEMENT SLOT DISPLACEMENT FROM CENTERLINE

Slot No.	Centerline Displacement (Inches)	Slot No.	Centerline Displacement (Inches)	Slot No.	Centerline Displacement (Inches)
1.....	0.007 Left	22.....	.039 R	43.....	.085 L
2.....	.007 Right	23.....	.041 L	44.....	.087 R
3.....	.008 L	24.....	.044 R	45.....	.088 L
4.....	.008 R	25.....	.046 L	46.....	.089 R
5.....	.009 L	26.....	.048 R	47.....	.090 L
6.....	.010 R	27.....	.050 L	48.....	.090 R
7.....	.011 L	28.....	.053 R	49.....	.089 L
8.....	.012 R	29.....	.055 L	50.....	.088 R
9.....	.014 L	30.....	.057 R	51.....	.086 L
10.....	.015 R	31.....	.060 L	52.....	.083 R
11.....	.017 L	32.....	0.062 R	53.....	.079 L
12.....	.019 R	33.....	0.064 L	54.....	.075 R
13.....	.021 L	34.....	.067 R	55.....	.070 L
14.....	.023 R	35.....	.069 L	56.....	.064 R
15.....	.025 L	36.....	.071 R	57.....	.059 L
16.....	.027 R	37.....	.074 L	58.....	.054 R
17.....	.029 L	38.....	.076 R	59.....	.049 L
18.....	.031 R	39.....	.078 L	60.....	.046 R
19.....	.033 L	40.....	.080 R	61.....	.043 L
20.....	.035 R	41.....	.082 L	62.....	.042 R
21.....	.037 L	42.....	.084 R	63.....	0.042 L
				Load.....	

Referring particularly to FIG. 8 and simultaneously to FIGS. 2 and 4, there is shown the curvature of reflector 24 of vertical antenna 5. For example, at 9375 megacycles, the focus of reflector 22 is at a point 15.0 along the positive X axis of FIG. 8. The curvature of the reflector is represented by the accompanying Table D, showing X and Y coordinates of the curvature. Particularly, point 1 along the curvature is seen from Table D to be +4.624" along the X axis and -7.538" along the Y axis. The other points 2-40 are similarly obtained from the accompanying Table D. The design of the curvature of the slant beam reflector is based on geometrical optics considerations. The standard technique appears in the literature, S. Silver, "Microwave Antenna Theory and Design," McGraw-Hill, New York, pp. 497-500, 1949; A. S. Dunbar, "Calculations of Doubly Curved Reflectors for Shaped Beams," Proc. IRE, vol. 36, pp. 1289-1296, October 1948, and H. Jasik, "Antenna Engineering Handbook," McGraw-Hill, New York, pp. 12-19 to 12-21, 1961. Referring particularly to Jasik, section 12-20 and solving the equation

$$\frac{\int_{\theta_1}^{\theta} P(\theta) d\theta}{\int_{\theta}^{\theta_2} P(\theta) d\theta} = \frac{\int_{\phi_1}^{\phi} I(\phi) d\phi}{\int_{\phi}^{\phi_2} I(\phi) d\phi}$$

where ϕ and θ are primary—and secondary—pattern angles and the subscript values correspond to the reflector limits and where the energy corresponds between primary $I(\phi)$ and secondary power beam pattern $P(\theta)$ is expressed by the above formula, the coordinates as shown in Table D are obtained. It is to be understood that for other operating frequencies the coordinates of the reflector will vary in accordance with known solutions of the above formula.

TABLE D.—VERTICAL REFLECTOR

Point	X (Inches)	Y (Inches)	Point	X (Inches)	Y (Inches)
1.....	4.624	-7.533	21.....	0.308	3.123
2.....	4.775	-7.192	22.....	0.373	3.755
3.....	3.714	-6.335	23.....	0.455	4.371
4.....	3.260	-6.454	24.....	0.554	5.031
5.....	2.817	-6.048	25.....	0.669	5.674
6.....	2.389	-5.615	26.....	0.801	6.322
7.....	1.988	-5.152	27.....	0.946	6.976
8.....	1.618	-4.660	28.....	1.109	7.637
9.....	1.290	-4.137	29.....	1.288	8.305
10.....	1.033	-3.587	30.....	1.484	8.980
11.....	0.811	-3.016	31.....	1.698	9.664
12.....	0.635	-2.430	32.....	1.932	10.358
13.....	0.495	-1.832	33.....	2.186	11.061
14.....	0.387	-1.227	34.....	2.460	11.776
15.....	0.309	-0.616	35.....	2.757	12.503
16.....	0.256	0.000	36.....	3.076	13.243
17.....	0.227	0.619	37.....	3.421	13.996
18.....	0.218	1.241	38.....	3.793	14.764
19.....	0.229	1.866	39.....	4.193	15.549
20.....	0.260	2.493	40.....	4.623	16.351

It is to be understood that the specific embodiment described for producing shaped beams, is not the only means available for producing shaped beams. For example, other means for producing shaped beams having its significant radiation between 6° and 75° and being conically shaped are taught by Sletten et al. "Corrective Line Sources for Paraboloid," IRE Transaction on Antennas and Propagation, vol. AP-6, pp. 248-250, July 1958. Additionally, it is possible to produce shaped beams as shown in Jasik, "Antenna Engineering Handbook," particularly chapter 9, etc., and Silver, "Microwave Antenna Theory and Design," particularly chapters 12 and 13. It is, therefore, desired that this invention not be limited to any particular type means for producing shaped beams but rather be solely limited to the structure as claimed in the appended claims.

Referring particularly to FIG. 9, there is shown a 3D radar system in block form utilizing an inverted V-shaped beam antenna. There is shown a surface complex 50 having a transmitter 51 and a receiver 52 coupled to a duplexer 53 which, in turn, is coupled to slant antenna 54 of inverted V-shaped beam antenna 55. The combination being adapted to transmit a shaped beam along a small circle locus from slant antenna 54 and receive reflections from a target, such as aircraft 56, flying above the surface complex. Additionally, there is shown a second transmitter 57 and a receiver 58 coupled to a duplexer 59 which, in turn, is coupled to vertical antenna 60 of inverted V-shaped beam antenna 55. The combination being adapted to transmit a vertical shaped beam along a great circle from vertical antenna 60 and receive radiation reflections from a target, such as an aircraft 56. Additionally, there is shown a computer-display 61 adapted to provide range and azimuth information from reflections received from the vertical antenna which is scanning in the conventional two dimensional radar fashion. Furthermore, computer-display 61 is programmed to compute target height by first determining the elevation angle of the target from the equation

$$\sin F = \frac{\sin R}{\cos A} + \tan C \tan A$$

as taught in the explanation of FIGS. 2 and 3. Then the height of the target is computed from the known geometrical relationships given by the equation $r \tan A = \text{height}$ which is range times $\tan A = \text{height}$, where A is the elevation angle of the target craft with respect to the surface complex.

Other embodiments of the invention can include electronic beam scanning from a fixed aperture in lieu of mechanical rotation of the inverted V-beam antenna. Additionally, it is possible to obtain greater accuracies if more than two beams are used so as to provide additional redundant information. For example, three shaped slant beams can be used along with one vertical shaped beam so as to provide additional useable information.

This completes the description of the illustrative embodiments of the present invention. It will be noted from the foregoing that the present invention provides an antenna system permitting accurate measurement of steeper elevation angles than heretofore in the state of the art and simultaneously provides greater angular response sensitivity due to beam orientation as illustrated in the preferred embodiments. Accordingly, it is desired that this invention not be limited to the particular details of the embodiments disclosed except as defined by the appended claims.

What is claimed is:

1. An inverted V-beam antenna system adapted to scan a portion of a spherical volume of space to provide accurate elevation measurements over a substantially 90° range of angles and simultaneously provide the greatest sensitivity of measurement at the low elevation angles comprising means for providing a plurality of shaped beams, and means for directing at least one of said plu-

ality of shaped beams along a small circle arc intersecting the zenith of said volume such that the spread between said at least one beam and at least one other beam decreases with increasing height above said antenna system.

2. An inverted V-beam antenna system comprising a first shaped beam antenna having a reflector and a feed, said reflector and feed, in combination, providing a first shaped beam oriented along a great circle arc, and a second shaped beam antenna having a reflector and feed, said second reflector and feed, in combination, providing a second shaped beam along a small circle arc such that the spread between said beams always decreases with increasing height above said antenna system so as to provide inverted V-beam.

3. An inverted V-beam antenna system comprising a first shaped beam antenna, and a second shaped beam antenna, said first and second antennas providing shaped beams along small circle arcs such that the spread between said shaped beams always decreases with increasing height above said antenna system so as to produce an inverted V-beam.

4. An inverted V-beam system adapted to scan a portion of a spherical volume of space comprising a first shaped beam antenna, a second shaped beam antenna, and means for simultaneously rotating said first and second antennas, said first antenna providing a vertical beam having its principle radiation directed along a great circle arc intersecting the zenith, said second antenna providing a slant beam having its principle radiation directed along a small circle arc intersecting the zenith of said volume such that the spread between said beams decreases with increasing height above said antenna system.

5. An inverted V-beam antenna system adapted to scan a portion of a spherical volume of space comprising means for providing a plurality of shaped beams, and means for electronically scanning at least one of said plurality of beams along a small circle arc intersecting the zenith of said volume such that the spread between said at least one beam and at least one other beam decreases with increasing height above said antenna system.

6. A beacon system comprising a surface complex, said surface complex comprising a transmitter, a power divider coupled to said transmitter, first and second shaped beam antennas, each coupled to said power divider, means for simultaneously rotating said first and second antennas, said first and second shaped beam antennas radiating a pair of shaped beams, and including means for directing at least one of said shaped beams along a small circle arc such that the spread between said pair of beams decreases with increasing height above said antennas, and a vehicle means in a spaced relationship to said complex, said vehicle means comprising means for detecting said pair of shaped beams radiated from said first and second antennas.

7. A beacon guidance system adapted to scan a portion of a spherical volume of space for helicopter landing operations comprising a surface based complex, said complex comprising a transmitter, a first vertical shaped beam antenna coupled to said transmitter, a second slant shaped beam antenna coupled to said transmitter, said first antenna adapted to radiate a first shaped beam oriented along a great circle arc, intersecting the zenith of said volume, said second antenna adapted to radiate a second shaped beam oriented along a small circle arc intersecting the zenith such that the spread between said beams decreases with increasing height above said antennas, an airborne vehicle adapted for flight in a spaced relationship to said surface based complex, said vehicle comprising means for detecting said first and second shaped radiated beams.

8. A beacon system adapted to scan a portion of a spherical volume of space comprising means for providing energy for radiation, means for providing a first shaped beam along a great circle intersecting the zenith of said volume and being coupled to said means for pro-

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viding energy for radiation, means for providing a second shaped beam along a small circle intersecting the zenith such that the spaced between said beams decreases with increasing height and being coupled to said means for providing energy for radiation, and vehicle means in a spaced relationship to said means for providing said first and second shaped beams, said vehicle means comprising means for detecting said first and second beams.

9. A beacon system as claimed in claim 8 including means for scanning said first and second shaped beams.

10. A system adapted to scan a portion of a spherical volume of space for detecting a target comprising means for providing energy to be radiated, means for providing a first shaped beam along a great circle intersecting the zenith of said volume and being coupled to said means for providing energy to be radiated, means for providing a second shaped beam along a small circle intersecting the zenith such that the spread between said beams decreases with increasing height and being coupled to said means for providing energy to be radiated, and means for determining range, height and azimuth of said target from said system comprising means for detecting first and second beam target reflections.

11. A system adapted to scan a portion of a spherical volume of space for detecting a target comprising means for providing energy to be radiated, means for radiating a plurality of shaped beams coupled to said means for providing energy, and means for orienting at least one of said plurality of shaped beams along a small circle arc intersecting the zenith of said volume such that the spread between said at least one beam and at least one other beam decreases with increasing heights, and means for detecting target reflections from said plurality of radiated beams.

12. A three dimensional radar system adapted to scan a portion of a spherical volume of space for determining range, height and azimuth of a target comprising means for providing energy to be radiated, means for providing a slant beam along a small circle arc intersecting the zenith and being coupled to said means for providing energy to be radiated, means for providing a vertical beam along a great circle arc intersecting the zenith of said volume such that the spread between said beams decreases with increasing height and being coupled to said means

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for providing energy to be radiated, and means for receiving shaped beam radiation reflections from said target.

13. A radar system adapted to scan a portion of a spherical volume of space comprising means for providing energy to be radiated, means for radiating a plurality of shaped beams, and means for orienting at least one of said shaped beams along a small circle arc intersecting the zenith of said volume such that the spread between said at least one beam and at least one other beam decreases with increasing height and means for receiving radiation reflections from said shaped beams hitting a target.

14. A beacon system adapted to scan a portion of a spherical volume of space for helicopter landing operations comprising means for providing energy to be radiated, means for radiating a plurality of shaped beams, and means for orienting at least one of said shaped beams along a small circle arc intersecting the zenith of said volume such that the spread between said at least one beam and at least one other beam decreases with increasing height, and means for detecting said beams positioned at a spaced relationship with respect to said means for radiating a plurality of shaped beams.

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CHESTER L. JUSTUS, *Primary Examiner.*

E. T. S. CHUNG, P. M. HINDERSTEIN,
Assistant Examiners.